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AFAMRL-TR-80-126

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FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
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Primary task interference and poor operator acceptance are problems associated with secondary task measures of aircrew workload which limit their usefulness during the later stages of system development. A possible solution to these problems would be to design secondary tasks which are an integral part of normal operator duties and retain the properties of valid measurement tasks. This report describes a concept of using realistic radio communications activities as subsidiary workload measurement tasks in R&D simulations and actual flight tests. In order to devise a generalized method of developing communications

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tasks with controlled levels of added workload which could be tailored to specific system and mission contexts, three methods of workload scaling were applied to 13 communications tasks typical of those occurring in the A-10 aircraft. The first technique provided workload estimates based on the information transmission demands of communications activities. Information theoretical metrics were applied to the perceptual decisions and manual action decisions required in response to incoming messages. In a second scaling effort, this approach was supplemented by estimates of the additional contribution to workload of memory demands, information gathering activities, and instruction complexity, which were not assessed by the information theoretical measures. Pilot opinions of the workload associated with messages contained in the communications tasks were obtained by a paired comparisons technique. The results of the initial analytical scale and the weightings derived from this procedure were combined to form a hybrid analytical scale. The final scaling approach relied on subjective estimates of the workload associated with complete communications tasks. Pilot rankings of the tasks were used to derive a scale based on modified Thurstonian procedures. Nonparametric correlational procedures revealed considerable agreement among the results of the three scaling methods.

The final section of this report outlines a plan for experimental dual task performance studies to test the sensitivity of the communications tasks to primary task workload and to evaluate the three a priori scaling methods.

PREFACE

This report describes the development and scaling of pilot radio communications activities for use as operationally oriented subsidiary workload measurement tasks. The report was prepared in part by Systems Research Laboratories, Inc. (SRL), 2800 Indian Ripple Road, Dayton, Ohio 45440, under Contract F33615-79-C-0503. The work was performed in support of AFSC Project 7184, Man-Machine Integration Technology for the Air Force, for the Air Force Aerospace Medical Research Laboratory (AFAMRL), Human Engineering Division (HE), Wright-Patterson Air Force Base, Ohio 45433; and of AFSC Project 7930, Advanced Crew Technology, for the United States Air Force School of Aerospace Medicine (USAFSAM), Advanced Crew Technology Division (VN), Brooks Air Force Base, Texas 78235.

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INTRODUCTION

CONCEPTUAL BACKGROUND

Mental workload is a problem of increasing importance in modern airborne weapon systems. The expanding capabilities of military aircraft achieved through the incorporation of sophisticated technology are responsible for a proportional growth in the monitoring and decision making responsibilities of the individual crew member. As these task demands continue to accelerate, human information processing capacities and limitations become more critical determinants of total system performance. Consequently, in order to insure mission success, a variety of accurate and reliable methods are needed to assess aircrew workload at all levels of system development.

Because mental processes are not directly observable, a number of subjective, physiological, and performance indices have been offered as measures of mental workload. Concerns for quantification and reliability make objective measures of workload preferable to subjective estimates in many applied settings. The secondary task methodology is the most widely used objective measure of workload and is the technique with the greatest amount of research support (Wierwille and Williges, 1978). The use of secondary tasks is based on the assumptions that an upper bound exists on the ability of the human operator to process information and that the mental resources which form this limited capacity can be shared among tasks. The methodology requires the operator to perform an extra task along with a primary task of interest. Workload measures are derived by comparing single and dual task performances.

As noted by Ogden, Levine, and Eisner (1979), secondary tasks can be used to estimate workload in two general ways. In one type of experimental situation, an additional task is added to induce stress. The purpose of this manipulation is to increase total workload in order to improve the sensitivity of primary task performance measures. The more traditional application of the secondary task is to derive a measure of spare mental capacity. In this case, the primary task receives priority while the secondary task is relegated to residual processing resources. An estimate of primary task workload is made by assessing the magnitude of the difference in secondary task performance between the single task and the dual task conditions.

The workload literature documents a variety of tasks that have been used within these two paradigms with varying degrees of success. In order to provide some guidance for the selection of appropriate tasks, Knowles (1963) listed several characteristics which secondary tasks should have in order to maximize the sensitivity and validity of measurement.[1] Tasks should be easily learned and scorable, and task demand should be manipulable over a range of difficulty. In order to eliminate peripheral interference, secondary tasks should not share input or output modalities with the primary task. Furthermore, secondary tasks which tap a variety of information processing functions are preferable to those which load only specific cognitive structures. Ogden et al. (1979) added the important criterion of acceptance by the operator. Whether used to induce stress or to measure reserve capacity, secondary tasks should be chosen to achieve face validity and congruence with the overall performance situation. Operator acceptance is an especially crucial factor in operational environments where failure to integrate the extra task would lead to the contamination of results because the operator either neglects the task or allows it to assume an artificially high priority.

Although some secondary tasks come close to meeting many of these criteria in a given situation, additional problems arise with most tasks when their use at different stages of system development is taken into consideration.

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[1] The criteria discussed by Knowles (1963) are specific to practical issues associated with secondary task methodology. Theoretical considerations may also place restrictions on task selection and interpretation. These factors are addressed in Section V of this report.

Schiflett (1976) noted that the majority of workload measures were developed for, and are most applicable to, the early design stage in which experimentation is confined to a laboratory setting. At the level of operational test and evaluation or even during high fidelity simulation, these measures often become difficult or impractical to employ. Wierwille and Williges (1978) reviewed several factors which affect the feasibility of using various workload measurement techniques in an in-flight environment. Physical variables such as the size, weight, and portability of experimental equipment are obvious problems that can be solved with further technological development. However, the potential for intrusion on primary flight control performance is a danger that would accompany the use of nearly all traditional secondary tasks. The probability of such interference would be greatest when the added task is artificial and novel in nature and, therefore, apt to cause involuntary distraction from critical activities.

The combined problems of operator acceptance and intrusion severely limit the use of objective secondary task measures of workload in high fidelity flight simulation or operational test environments. At best, presently available laboratory tasks have questionable validity in these situations, and at worst could impair flight safety. For these reasons, workload measurement at the critical later stages of system evolution is often performed using relatively informal and qualitative techniques.

SUBSIDIARY COMMUNICATIONS TASKS

A secondary task which would be suitable for assessing mental workload or for increasing workload stress during high level simulation or in-flight test should be fully integrated with existing system hardware and with the crew member's conception of his task and mission environment. By its nature, such a task would be a realistic component of crew station activity, yet one which is logically and experimentally separable from the primary flight performance of interest. The effort described in this report was directed toward developing methods for adapting radio communications activities for use as secondary loading tasks which would fulfull these criteria while providing a quantifiable means of measuring the workload of aircrew members.

The aircraft radio communications which appear to be most amenable to this application are those initiated by a message sent from any of a number of combat elements to the pilot whose level of workload is to be assessed. Upon detection and identification of a relevant message, the pilot must engage in verbal and manual actions in response to the information that he receives. Such tasks closely resemble the nonadaptive discrete secondary tasks used in numerous workload studies (see Wierwille and Williges, 1978) and, upon further analysis, appear to embody many properties of a good workload measure. Initially, it is apparent that communications activities call upon a wide range of perceptual, cognitive, and motor abilities and have the potential of being varied along several dimensions of difficulty. Furthermore, the opportunity for peripheral input or output interference is minimized. Communications tasks occupy only the auditory input channel, thereby eliminating effects of sensory interference which would reduce the validity of any visual secondary task. Likewise, the chance for output interference is obviated since verbal responses are uniquely assigned to communications functions in present aircraft systems and all manual switching activities are designed to be dealt with by the pilot's hand not required for aircraft control. From the hardware point of view, communications tasks are advantageous secondary tasks because they require no additional displays or controls for the pilot; and they permit the experimenter to control task presentation and to record performance data using existing communications channels.

Most importantly, communications tasks are already an integral part of the pilot's in-flight duties. As a result, lengthy training requirements are eliminated and high face validity is achieved. Furthermore, the realistic nature of the task makes artificial task interactions and intrusion improbable because the pilot has predetermined attentional priorities assigned to both communications and other cockpit functions.

The concept of using communications tasks to manipulate workload was tested informally during a recent study using an A-10 full-mission simulation (Spencer, 1979). While the pilots delivered stand-off weapons against tank targets, communications tasks requiring radio switching, radio tuning, and verbal responses were presented in order to increase workload. Although no quantitative data were presented, Spencer reported that the effects of communications stressors on total system performance were operationally significant.

These suggestive results, combined with the urgent requirement for nonintrusive objective measures, stimulated the research to develop and validate the concept of using secondary communications tasks for workload assessment in R&D simulation. A primary goal was to devise communications tasks quantified with respect to workload and which would maintain a high level of operational realism. Accordingly, specific aircraft and mission types were selected to derive the source material to be used to generate communications tasks and to validate the resulting workload assessment methodology. The formulation of secondary communications tasks for A-10 air-to-ground missions is described in this report. Evaluation of these secondary tasks will be performed in limited and full scale mission simulation. If the results of the evaluation suggest that this approach is viable, additional tasks will be developed to fulfill other Air Force workload assessment requirements. Care will be taken to obtain review of such tasks by potential users to ensure that face validity and pertinence of the communications tasks are preserved.

The initial phase of task development involved the acquisition of source materials for the A-10 air-to-ground scenarios. Extensive interviews with a current Tactical Air Command A-10 pilot led to the compilation and organization of the 13 communications tasks shown in Appendix 1. The tasks were drawn from six scenarios representative of the types of communications which would occur as the pilot (Tiger 1) leaves his holding orbit outside the forward edge of battle area (FEBA), descends to terrain avoidance (TA) altitude, penetrates the FEBA, and completes the attack phase of the air-to-ground mission. The scenarios include identification, threat alert, traffic control, waypoint passage, jammed communications, and strike clearance activities. Each scenario contains 2 to 3 communications tasks. A task is defined as an entire logical sequence of verbal and manual activities initiated when the pilot receives a radio message from some other combat element. The combat elements contained in the source material are identified below.

Combat Elements	Radio/Freq.	Comments
TIGER 2	FM, 40.80	Another A-10 following in trail by 30 seconds
NAIL 4	UHF, Channel 1	Airborne Forward Air Controller (FAC)
PARADISE	VHF, 122.1	Airborne Warning and Control System (AWACS) Aircraft
POUNDER	VHF, 142.7	Army Strike Team Commander
DOGBONE	UHF, Channel 5	Another Army Strike Team Commander
FRIENDLY	Unknown until given	Another AWACS Aircraft

The manual responses required by the communications tasks involve the use of the UHF, VHF, FM, IFF, intercom, and transmit controls of the A-10 radio system. Appendix 2 contains an illustration of the relevant A-10 control panels and lists the switch positions and standard procedures relevant to the start of a mission.

THE SCALING PROBLEM

As noted previously, radio communications tasks such as those identified for the A-10 air-to-ground mission have many potential advantages over standard laboratory secondary tasks. Among the most important of these are the fidelity and operational orientation of the communications tasks. These features should improve acceptance by professional pilots and decrease the possibility of irrelevant interference with the behavior of interest. However, a serious disadvantage of the proposed methodology is that the very realism of communications activites makes precise experimental control or higher order scaling of task workload difficult.

Traditional laboratory secondary tasks are designed to impose constrained and highly describable stimulus and response demands upon the performer. The parameters of such tasks are easily varied to manipulate task loading in a precise fashion. Normally, these tasks contain abstract stimulus elements, and the effects of prior experience can be minimized to permit control of expectancies. In addition, secondary tasks often are selected so that they can be presented repeatedly to obtain a precise level of loading during an experimental session.

In comparison, realistic radio communications activites are complex information processing tasks which vary along many more loading dimensions than typical laboratory tasks. Linguistic stimuli are relatively unstructured, and complex verbal and manual response sequences are difficult to vary in a controlled manner. Furthermore, any attempt to use repeated presentation of single tasks or to constrain the constituents of stimuli and responses would detract from the face validity of secondary communications tasks.

Whether used to generate workload stress or to measure reserve capacity, the value of the communications task methodology would be compromised unless a valid estimate of the workload associated with each task can be obtained. Assuming that an ordinal or, perhaps, interval scale could be derived for the workload associated with communications tasks, it would be possible to combine tasks realistically so that controlled levels of additional loading could be produced to meet the needs of specific simulations or flight tests.

Several methods of scaling can be applied to communications tasks to provide quantified workload estimates which do not require laboratory performance testing. Although all of these methods are based on sound theoretical foundations, each has unique sources of error associated with it and may not provide a completely adequate assessment of workload. Consequently, in order to maximize the probability of obtaining valid workload estimates, multiple scaling techniques should be used. The following sections of this report document the use of three scaling techniques which rely on analytical, subjective, and hybrid methods of workload estimation (see Table 1). The object of these efforts was to generate alternative a priori methods of communications task workload scaling which could be used to design workload assessment methodologies tailored to specific systems and missions. The criterion for comparative evaluation of these techniques will be derived from the results of performance based tests of the communications tasks which will be performed during a later phase of this project. It should be noted that although the A-10 mission source tasks were the focus of these efforts, the scaling methods were designed to be applicable to other mission and system contexts.

TABLE 1. APPROACHES TO THE DEVELOPMENT OF A COMMUNICATIONS WORKLOAD SCALE

I.	ANALYTICAL SCALING
	Information Theoretic Analysis of Information Transmission Requirements
II.	HYBRID SCALING
	Supplementation of Estimates of Information Transmission Requirements by Measures of Additional Information Processing Requirements
III.	SUBJECTIVE SCALING
	Pilot Workload Ratings and Categorization

Section 2

ANALYTICAL SCALING

INFORMATION THEORY

Analytical methods of estimating workload rely upon the postulates of models or theories of human perceptual, cognitive, and motor processes in order to quantify the information processing demands of a task. The analytical technique used in this scaling effort was based on the theory of information (Shannon and Weaver, 1949). Briefly, information theory defines the transmission of information as the resolution of uncertainty concerning a set of events. In general, uncertainty is a logarithmic function of the number of alternative events that could occur. The information metric is the bit and refers to the number of binary decisions required to resolve uncertainty. Applied to the human operator, information theory offers a method of quantifying the information content of perceptual-motor tasks. Considerable experimental support is available to indicate that information processing time is a roughly linear function of the information transmission demand of a variety of tasks (see Fitts and Posner, 1967). The assumption made in the following analysis is that workload is partially a function of the uncertainty associated with communications task stimuli and responses.

ANALYSIS

The workload of any complex task can be considered a joint function of the rate of information presentation and of the complexity of the information processing required of the operator. Within the limits of realism set by the simulated missions, the rate of communications task presentation will be relatively easy to control and should not prove to be a significant problem when used to manipulate workload. The difficulty of scaling the workload of communications tasks stems from the multidimensional nature of the complexity parameter. From the operator's viewpoint, complexity depends upon the information content of the messages received and upon the nature of the cognitive activity required to translate incoming information to an appropriate set of responses. In order to quantify these psychological factors, at least two analytical approaches are required. The communications activities first must be ordered in terms of the amount of information contained in messages received and responses produced. Secondly, the scaling arrived at through the first approach must be weighted by obvious cognitive activities which contribute to the difficulty of processing. The primary purpose of the scaling effort reported here was to estimate the contribution of information transmission demands to the workload of communications activities.

The generic form of the initial communications request for each of the tasks found in the source material is as follows:

(1)	Identification of Intended Receiver	e.g., "Tiger 1"
(2)	Identification of Caller	e.g., "Paradise"
(3)	Instruction	e.g., "Squawk Ident"

Although each of these steps is not explicitly stated in all of the tasks, every communication requires the pilot to process information corresponding to all three. Resulting responses include both verbal and manual activities.

For the purposes of this analysis, the pilot's task can be broken down into a series of information processing decisions related to the three steps shown above. The number of processing decisions required by a particular task should be a measure of the contribution of information transmission demands to workload. As dictated by formal information theory, information is transmitted when uncertainty is resolved concerning the identification and response activities contained in an incoming message. Bit values (H) can be calculated for the activities required of the pilots in communications tasks by estimating the number of alternatives (N) associated with each processing decision ($H = \log N$).

Two general types of decisions must be made by the pilot (see Table 2). Once he has detected the presence of an incoming message on any of his monitored frequencies, he must make two <u>perceptual decisions</u>. First, he must determine whether the message is intended for him or some other combat element. Assuming equal *probability of alternatives*, there are six persons who could be called. Thus, the resolution of the uncertainty associated with this decision would result in the transmission of $\log_2 6 = 2.58$ bits. In order to select an appropriate transmitting mode and frequency, the pilot must also identify the message's sender. Again, this would result in the transmission of an additional 2.58 bits.

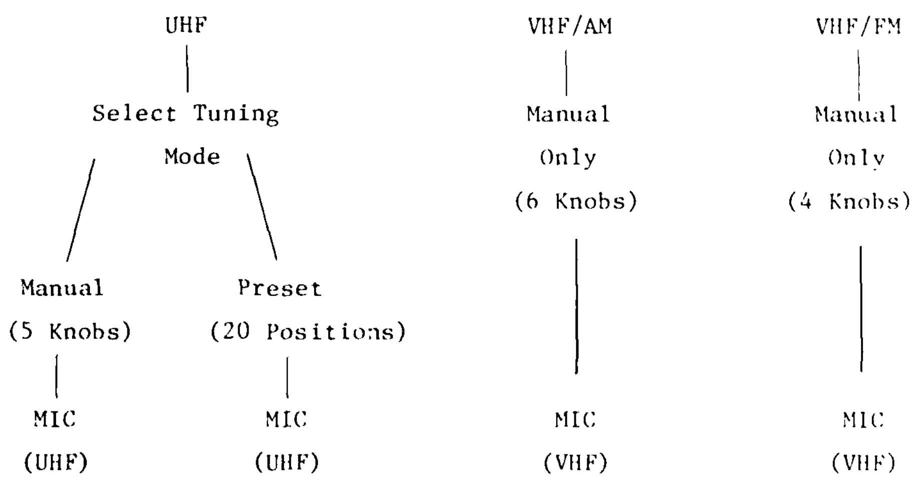
TABLE 2. COMMUNICATIONS PROCESSING DECISIONS

I.	<u>PERCEPTUAL DECISIONS</u>	
	A.	Identification of Intended Receiver
	B.	Identification of Caller
II.	<u>ACTION DECISIONS</u>	
	A.	Manual
	B.	Verbal

Following these perceptual decisions, the pilot must make <u>action decisions</u> in response to the instructions he receives. Action decisions may entail manual or verbal responses. Manual communications activities involve switch actions on the IFF, Intercom, UHF, VHF, and FM panels, and on the MIC switch located on the throttle control of the A-10 (see Appendix 2). The information transmission requirements of these actions can be quantified by investigating the sequence of manual responses and the number of alternative actions possible for each response designated by an explicit or implied command. In performing these calculations, equiprobability and independence of manual decisions were assumed as well as complete knowledge of control location. As an example of these computations, consider the IFF panel. Relevant instructions may require a single push of the IDENT switch or could involve changing IFF codes on the thumbwheel controls. Pushing IDENT involves the transmission of a single bit. However, when a code change is required, the pilot must first select the appropriate mode (1 bit), then dial-in a four-digit code (12 bits) on the thumbwheels (if mode 3A is chosen), and finally push IDENT (1 bit). A total of 14.00 bits is transmitted in this sequence of activities (see Table 3).

The pilot is also required to perform manual switch actions to engage in voice communications in response tc an implied instruction (i.e., identifying sender and switching to his frequency) or to an explicit instruction to call another combat element. The general sequence of activity on the communications panels is shown below.

MODE SELECT



The number of alternative actions for each switch activity was calculated by inspection of the panels and from knowledge of allowable settings on each panel. The information metrics calculated for each manual response are shown in Table 3.

TABLE 3. INFORMATION THEORETICAL CALCULATIONS

	<u>Perceptual Decisions</u>	
A.	Possible Senders (6)	(2.585 bits)
	1. Tiger 2	
	2. Nail 4	
	3. Paradise	
	4. Pounder	
	5. Dogbone	
	6. Friendly	
B.	Possible Receivers (6)	(2.585 bits)
	Tiger 1 plus all of the above minus 1	
	<u>Action Decisions</u>	
A.	Simple Single Switch Action (Ident) (2)	(1.000 bit)
	1. Yes	
	2. No	
B.	IFF Code	
	$\left.\begin{array}{l}\text{1. Mode 1}\\ \text{2. Mode 3A}\end{array}\right\}\text{(2)}$	(1.000 bit)
	If mode 1: two dials with 8 and 4 alternatives, respectively	(5.000 bits)
	If mode 3A: four dials with 8 alternatives each	(12.000 bits)
C.	Select Comm Mode (3)	(1.585 bits)
	1. VHF AM	
	2. VHF FM	
	3. UHF	
D.	Mic Switch (2)	(1.000 bit)
	1. Up (VHF)	
	2. Down (UHF)	

TABLE 3. INFORMATION THEORETICAL CALCULATIONS (continued)

E. Select Preset UHF Channel	(4.322 bits)
Twenty channels	
F. Release Chaff and Flares	
1. Chaff (2)	(1.000 bit)
a. Yes	
b. No	
2. Flares (2)	(1.000 bit)
a. Yes	
b. No	
G. Select VHF Frequency	(11.966 bits)
Six dials with 0, 5, 10, 10, 4, and 2 alternatives, respectively	
H. Manual UHF Channel Select	
1. Select Mode	(1.585 bits)
a. Preset	
b. Manual	
c. Guard	
2. Select Frequency	(12.966 bits)
Five dials with 2, 10, 10, 10, and 4 alternatives, respectively	
I. Manual FM Channel Select	(11.229 bits)
Four dials with 6, 10, 10, and 4 alternatives, respectively	
J. Jammed Comm.	(1.000 bit)
1. Change channels	
2. Stay on same channel	

The second type of action decision which is required by an instruction involves verbal responses. An overview of the verbal activities contained in the source material revealed two general types of responses. The simplest activity is a confirmation of a message or switch action. This activity may be confined to a single word of acknowledgement ("ROGER") or may involve the repetition of an instruction. In either case, the task involves pure information conservation and, at this level of analysis, requires the processing of a single unit of information. The second type of verbal response requires the pilot to select a receiver (2.585 bits) and report a specific piece of mission-related information. In some cases reporting is immediate, while in others there is a time delay between the original instruction and the response. Furthermore, there are obvious differences in the workload associated with gathering the information content of the report. These additional factors influencing workload cannot be assessed by the information metric since it is limited by the assumption of complete knowledge of report content. Therefore, only a single bit was added to the calculation for the loading attributable to the reporting activity.

The calculations of the information transmission requirements for each of the tasks in all scenarios are shown in Appendix 3.

A number of limitations to the analytical approach used to scale loading must be recognized. First, somewhat tenuous assumptions were made concerning the independence of sequential activities and the probability distributions of alternative actions. Second, the information metric could not be rigorously applied to verbal activities because of the inability to define the level of uncertainty associated with speech communication. Finally, as noted earlier, even under ideal conditions, measures of information transmission requirements do not account for the workload contributed by the <u>nature</u> of the information processing activities necessary to transmit information. Variables which require further consideration include running memory demands which play a role in scenarios such as waypoint passage, and the loading associated with the specific information gathering activities reflected in the content of verbal report responses. Despite the limitations, this initial attempt at scaling produced a wide range of workload estimates when applied to the communications tasks taken from the source material. Table 4 summarizes the results of the analysis.

TABLE 4. SUMMARY OF ANALYTICAL SCALING EFFORT

Communications Scenario/Task	Information Transmission Requirement (Bits) Perceptual	Verbal	Manual	Total
I. IDENTIFICATION DEMAND				
Task 1	5.170	0	1.000	6.170
Task 2	5.170	1.000	16.585	22.755
Task 3	5.170	3.585	9.644	18.399
II. THREAT ALERT				
Task 1	5.170	1.000	4.585	10.755
Task 2	5.170	4.585	10.644	20.399
III. TRAFFIC CONTROL				
Task 1	5.170	1.000	4.170	10.340
Task 2	5.170	3.585	17.136	25.891
IV. WAYPOINT PASSAGE				
Task 1	5.170	3.585	2.000	10.755
Task 2	5.170	6.170	19.136	30.476
V. JAMMED COMMUNICATIONS				
Task 1	5.170	2.585	2.000	9.755
Task 2	5.170	8.755	10.907	24.832
VI. STRIKE CLEARANCE				
Task 1	5.170	6.170	3.000	14.340
Task 2	5.170	11.340	8.170	24.680

Section 3

SUPPLEMENTARY MEASURES OF THE INFORMATION PROCESSING DEMANDS OF COMMUNICATIONS REQUESTS

PROCESSING COMPLEXITY

The information theoretical measures used in the initial attempt to scale communications workload provide a basic index of the information transmission requirements of manual and verbal tasks. However, such measures do not account for the contribution to workload of the amount and complexity of the processing activity needed to produce acceptable performance. The problem is illustrated in past attempts to apply information theory to choice reaction time tasks. Early findings suggested that the time required to produce a response was a simple increasing linear function of the information transmitted (Hyman, 1953). However, later research revealed that such factors as learning, stimulus-response compatibility, and the size and nature of transformations on stimulus information could vary the slope of this function dramatically (Fitts and Posner, 1967). Similarly, complex tasks such as those performed in a tactical communications scenario have workloads which are controlled by both stimulus and response information and the amount and type of processing necessary to convert stimulus information to an appropriate response.

The purpose of the effort described in this report was to develop a method of estimating the additional contributions to workload of information gathering activities, memory demands, and instruction complexity, not assessed by information theoretical measures. An examination of the communication activities in Appendix I revealed three general factors which may add to the workload associated with communications tasks. First, in some of the tasks, the pilot is required to engage only in specific manual switch actions or limited verbal behavior. However, other instructions demand that he perform aircraft control maneuvers or gather information from cockpit displays and from the external environment. Second, many of the tasks require the pilot to retain information in memory and to provide a verbal report at a later time. Finally, on some occasions, more than one instruction is delivered in a single message. Each of these activities introduces an extra processing demand which must be represented in an ordinal scale of workload.

In order to estimate the magnitude of these workload components, 15 specific messages were extracted from the original 13 communications tasks (see Table 5).

TABLE 5. MESSAGES EXTRACTED FROM COMMUNICATIONS TASKS

	Origin	Message
(1)	AWACS	Report SAMS.
(2)	AWACS	Descend to base plus 3.
(3)	AWACS	Descend to base plus 3, turn 90 degrees right.
(4)	AWACS	Descend to base plus 3, hold for 1 minute. Report at altitude.
(5)	AWACS	Descend to base plus 3, turn 90 degrees right, hold for 1 minute. Report at altitude.
(6)	FAC	Call 1 minute out of BRAVO.
(7)	FAC	Call FRIENDLY 1 minute out of BRAVO on UHF 132.1.
(8)	FAC	Call IP.
(9)	FAC	Call in hot at POP.
(10)	FAC	Call target in sight.
(11)	FAC	Call clear to TIGER 2.
(12)	AWACS	Squawk IDENT.
(13)	AWACS	Squawk 3, 0400.
(14)	FAC	Go to UHF 5.
(15)	TIGER 2	Break left, SAM at 6 o'clock.

An *a priori* analysis of these messages along the dimensions described previously resulted in the breakdown shown in Table 6.

TABLE 6. DIMENSIONAL ANALYSIS OF MESSAGES

Message	Memory Demand	Information Gathering: Inside Cockpit	Information Gathering: Outside Cockpit	Number of Instructions
1	--	√	√	1
2	--	√	--	1
3	--	√	--	2
4	√	√	--	3
5	√	√	--	4
6	√	√	√	1
7	√	√	√	2
8	--	--	√	1
9	--	--	√	1
10	--	--	√	1
11	--	--	√	1
12	--	--	--	1
13	--	--	--	1
14	--	--	--	1
15	--	--	--	1

Inspection of this table indicates that specific messages vary along each dimension and that while some of the messages require little extra processing activity, others appear to demand a considerable investment of mental resources.

Because of the multidimensional nature of the workload associated with these messages and the difficulty of quantitatively specifying the loading induced by each task, a structured subjective approach was taken to estimate overall information processing workload.

METHOD

A paired comparisons technique was designed to obtain pilot opinions of the workload associated with the 15 messages extracted from the communications tasks. Each of the messages was paired with each of the others to yield $\frac{N(N-1)}{2}$ or 105 comparisons. The paired messages were randomly ordered and arranged in booklet form. During test administration, 32 current A-7 and A-10 pilots were asked to examine each pair and to indicate with a check mark which of the two messages entails the higher workload. Appendix 3 contains the instructions for the paired comparisons evaluation and a sample page from the test booklet.

RESULTS

The data were subjected to the analysis described by Nunnally (pp. 51-55, 1967) to derive an interval scale of workload based on Thurstone's (1927) Law of Comparative Judgment. Accordingly, a cross matrix was formed showing the proportions of the pilots who rated each message greater in workload than each of the others (see Table 7). The technique required the assumption that each message would be judged greater than itself half of the time, so that .5 is placed along the diagonal of the table. The proportions were then converted to normal deviates (Z scores).

Assuming that judgment error is normally distributed about the "true" workload scale value, Thurstone's arguments demonstrate that the normal deviates serve as the interval separating the workloads of two messages. The error in the normal deviate between any two messages is reduced by summing the Z scores in each column and deriving the mean. The resulting value for each message is the normal deviate expressed about the average workload in the set. To eliminate negative values from the final scale, the absolute value of the largest negative value was added to each of the scale values. The resulting scale is shown in Table 8. The unit of measurement can be interpreted as one standard deviation of perceived difference in workload. An informal interpretation of these data with

TABLE 7. PROPORTIONS OF PILOTS WHO RATED MESSAGES IN COLUMNS HIGHER IN WORKLOAD THAN MESSAGES IN ROWS (N = 32)

Messages*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		.45	.55	.58	.60	.59	.65	.30	.35	.37	.26	.19	.35	.26	.45
2	.55		.84	.87	.87	.77	.74	.31	.50	.36	.37	.16	.43	.24	.58
3	.45	.16		.84	.86	.55	.74	.19	.29	.37	.34	.13	.24	.19	.52
4	.42	.13	.16		.81	.33	.48	.13	.17	.19	.20	.13	.16	.13	.50
5	.40	.13	.14	.19		.35	.40	.13	.16	.26	.19	.13	.16	.13	.50
6	.41	.23	.45	.67	.65		.87	.17	.23	.32	.16	.16	.32	.27	.67
7	.35	.26	.26	.52	.60	.13		.13	.23	.31	.14	.13	.28	.16	.59
8	.70	.69	.81	.87	.87	.83	.81		.81	.62	.65	.55	.74	.57	.68
9	.65	.50	.71	.83	.84	.77	.77	.19		.47	.57	.30	.73	.56	.72
10	.63	.64	.63	.81	.74	.68	.69	.38	.53		.65	.45	.70	.52	.74
11	.74	.63	.66	.80	.81	.84	.86	.35	.43	.35		.47	.69	.58	.73
12	.81	.84	.87	.87	.87	.84	.87	.45	.70	.55	.53		.87	.66	.67
13	.65	.57	.76	.84	.84	.68	.72	.26	.27	.30	.31	.13		.22	.58
14	.74	.76	.81	.88	.87	.73	.84	.43	.44	.48	.42	.44	.78		.65
15	.55	.42	.48	.50	.50	.33	.41	.32	.28	.26	.27	.33	.42	.35	

*See Table 5

TABLE 8. DERIVED WORKLOAD SCALE VALUES FOR MESSAGES EXTRACTED FROM A-10 COMMUNICATIONS TASKS

Message Number*	Value
1	.837
2	.493
3	.855
4	1.249
5	1.372
6	.909
7	1.192
8	.032
9	.354
10	.330
11	.284
12	0
13	.625
14	.229
15	.923

*See Table 5

respect to the four dimensions of processing listed in Table 6 was accomplished by computing mean scale values for each factor. Messages containing memory demands had a mean workload scale value of 1.180 in comparison to .451 for those messages without a memory component. Instructions requiring the acquisition of information from the visual environment outside the cockpit received a mean value of .562 while those requiring information gathering from visual displays in the cockpit had a mean value of .987. In contrast, messages lacking information gathering demands averaged only .444. This finding is of special interest since it might have been expected that acquiring information from a complex visual scene would present a greater workload than obtaining information from structured displays. Instead, it appears that perceived workload is reduced when pilots are able to use concrete information from the "real world" to fulfill the demands of radio communications requests.

An initial inspection of the mean scale values for messages containing differing numbers of instructions also revealed a clear trend. Messages with only one instruction had a mean value of .456. Those with two instructions averaged 1.023 on the scale, and those with three or four instructions received values of 1.249 and 1.372, respectively.

The informal comparisons discussed above are of limited value since the dimensions of complexity are overlapped in many of the messages. In order to estimate the contributions of each extra processing factor, a simple linear additivity model of workload was adopted. That is, it was assumed that combinations of these dimensions in specific messages do not interact in unique ways and that a given dimension will impose the same degree of workload regardless of its combination with other dimensions. The analysis was performed by summing the scale values of the messages which contained each of the seven factors contributing to workload. The dimensions then were used to generate linear equations in which the summed effects of each relevant factor were equal to the total scale value. For example, the memory dimension is present in four messages (4, 5, 6, and 7). The summed workload scale values for these messages is 4.722. This sum is a result of the combination of the effects of the four memory components and of the other factors operating in the messages.

Four of the commands with memory also required information acquisition inside the cockpit and two required "heads-up" visual activity. In addition, each instruction length was represented in the four relevant messages. Thus, the linear equation derived for the memory factor was:

$$4.722 = 4(M) + 4(IS) + 2(OS) + N + N + N + N.$$

where

M = memory demand

IS = inside cockpit information

OS = outside cockpit information

N_1 = one instruction

N_2 = two instructions

N_3 = three instructions

N_4 = four instructions

Seven simultaneous equations were generated in this manner based on the summed scaled values for each dimension. The solution for the equations yielded normalized scale values representing the workload contribution of each dimension (see Table 9).

TABLE 9. NORMALIZED WORKLOAD WEIGHTINGS FOR ADDITIONAL INFORMATION PROCESSING DIMENSIONS

Memory Demands	.340
Gathering Information from Cockpit Displays	.299
Gathering Information from External Environment	0
One Instruction	.386
Two Instructions	.593
Three Instructions	.609
Four Instructions	.732

The values obtained by this procedure were then used to modify the analytical scale derived in the preceding section of this report. A hybrid analytical scale representing both the information transmission demands and the information processing complexity of the source radio communications tasks was obtained by transforming the bit value obtained for each task to its normal deviate. The Z scores were then converted to eliminate negative values. Finally, the weights shown in Table 9 were added to the normalized task values as dictated by the presence of each added processing dimension in the communications task. The resulting scale is shown in Table 10.

TABLE 10. CALCULATION OF HYBRID ANALYTICAL SCALE VALUES

Communications Scenario/Task	Information Theory Analytical		Extra Processing Demand							Scale
						Instructions				
	Bits	Z Score	Memory	IS	OS	1	2	3	4	
I. Identification Demand										
Task 1	6.170	0				.387				.387
Task 2	22.755	2.139		.299		.387				2.825
Task 3	18.399	1.577		.299	0		.594			2.470
II. Threat Alert										
Task 1	10.755	.591			0	.387				.978
Task 2	20.399	1.835		.299	0		.594			2.728
III. Traffic Control										
Task 1	10.340	.538		.299		.387				1.224
Task 2	25.891	2.544	.340	.299					.733	3.916
IV. Waypoint Passage										
Task 1	10.755	.591	.340	.299	0	.387				1.617
Task 2	30.476	3.135	.340	.299	0	.387				4.161
V. Jammed Communications										
Task 1	9.755	.462				.387				.849
Task 2	24.832	2.407					.594			3.001
VI. Strike Clearance										
Task 1	14.340	1.054			0		.594			1.648
Task 2	24.630	2.388			0	.387	.594			3.369

Section 4
SUBJECTIVE SCALING

PILOT RANKING

Subjective methods of workload measurement are based on the assumption that the judged magnitude of the conscious experience of mental effort is at least partially related to the amount of information processing capacity required by the performance of a task. Models of workload which emphasize the relationship between physiological arousal and loading lend indirect support to this assumption (e.g., Kahneman, 1973). Unfortunately, subjective methods are often confounded by factors such as emotional state, experience, skill level, and simultaneous physical work. Although these sources of error are inherent to all subjective procedures, the experience of effort expenditure commonly reported during cognitive processing activities makes it reasonable to assume that structured subjective opinions may provide a valid estimate of the workload associated with radio communications tasks.

The method that was used to obtain quantifiable subjective evaluations of the workload of the source A-10 communications tasks is described in this section. A scale based on pilot rankings of the workload of complete communications tasks was used for comparison to the hybrid and analytical scales obtained in the previous scaling efforts.

METHOD

Thirty-one A-7 and A-10 pilots were briefed on a hypothetical air-to-ground attack mission scenario. The briefing identified the code names for various combat elements contained in the source tasks and outlined standard procedures relevant to communications activities. The pilots were then asked to inspect the 13 A-10 source tasks in order to estimate the total workload associated with each. The tasks were presented in the format shown in Appendix 1. However, the tasks were arranged in a random order on a foldout page to permit simultaneous examination and were identified only by the letters A-M.

In order to reduce the difficulty of the estimation task, the pilots were first asked to study the communications tasks and to categorize them on a five-point workload scale. They were then required to rank order all 13 tasks on the basis of workload.

RESULTS

Raw ranked data such as those obtained for this study do not reveal the magnitude of the underlying differences between ordered entities. However, if a reasonable assumption about the relation of ranks to numerical values can be made, it is possible to convert ranked data to interval scale values. One common assumption made in order to achieve this goal is that the true differences between adjacent items ranked near the extremes tend to be larger than differences between items falling near the middle in rank. Hays (1969) argued that when multiple judges are used to obtain rankings this assumption becomes reasonable and permits the development of a scale which has good agreement with scales derived by Thurstone's procedures.

According to Hays (1969), in order to derive scale values from ranks, the relative differences between N items are viewed as being similar to differences between Z values falling at the boundary points of N-1 equally probable intervals of a normal distribution. Thus, the interval between any two adjacent ranks should define an interval corresponding to $\frac{100}{N}$ percent of the cases in the distribution. Furthermore, in order to place the scale values in the midrange of the distribution, $\frac{100}{2N}$ is arbitrarily set as the percentage of cases below the value of the item ranked 1 and above the value of the item ranked N. These assumptions make the score difference between items ranked 1 and 2 or N and N-1 larger than the difference between items ranked in the center of the range. Interval data are derived by substituting Z values for the ranks. These are used to derive mean scale values based on the distribution of rankings produced by several judges.

The procedures described above were applied to the workload rankings obtained for the 13 A-10 communications tasks. Table 11 summarizes the data and the scale computations. The individual cell values in Table 11 indicate the number of pilots who assigned rank x to task y. The Z score rank (r) equivalents were computed by finding the Z score cutting off the lower $\frac{(r - .5)}{N}$ proportion of the area under the normal curve. Thus, for rank 1, the lower $\frac{(1 - .5)}{13}$ or .038 proportion of the normal curve corresponds to a Z value of -1.77. Scale values were calculated by multiplying the Z value for a rank by the number of pilots (f) who gave that rank to the task, summing across ranks, and dividing by the total number of pilots (31).

Thus, for Task 1 under Identification Demand the average scale value was equal to:

$$\frac{\Sigma(Zf)}{31} = \frac{17(-1.77) + 4(-1.2) + 8(-.87) + 1(-.62) + 1(.19)}{31} = -1.364$$

To eliminate negative scale values, the final scale was derived by adding the absolute value of the largest negative average value to each of the scores.

TABLE 11. CALCULATION OF SUBJECTIVE WORKLOAD VALUES FROM PILOT RANKINGS OF COMMUNICATIONS TASKS

	RANK 1	2	3	4	5	6	7	8	9	10	11	12	13	$\Sigma(Zf)$	Mean Z Score	Scale Value*
Identification [illegible]																
TA # 1	17	4	8	1	0	0	0	1	0	0	0	0	0	-42.28	-1.364	0
2	0	1	0	2	3	3	5	5	10	2	0	0	0	1.98	.064	1.428
3	0	0	0	1	0	0	3	5	2	13	4	2	1	16.84	.543	1.907
Threat Alert																
TA # 1	0	0	0	2	6	9	3	2	1	2	2	2	2	4.35	.140	1.504
2	0	0	0	2	1	6	7	3	7	3	1	1	0	4.52	.146	1.510
Traffic [illegible]																
TA # 1	0	2	6	10	6	2	2	0	1	0	1	1	0	-14.13	-.456	.908
2	0	0	0	0	0	0	1	2	1	3	7	15	2	30.27	.976	2.340
Waypoint [illegible]																
TA # 1	11	13	5	2	0	0	0	0	0	0	0	0	0	-40.66	-1.312	.052
2	0	0	0	0	0	1	1	0	4	1	4	4	16	37.19	1.200	2.564
Canned [illegible]nications																
TA # 1	0	2	4	5	10	6	3	1	0	0	0	0	0	-13.93	-.449	.915
2	0	0	0	0	0	0	1	1	1	5	10	5	8	32.55	1.050	2.414

TABLE 11. CALCULATION OF SUBJECTIVE WORKLOAD VALUES FROM PILOT RANKINGS OF COMMUNICATIONS TASKS (continued)

	RANK 1	2	3	4	5	6	7	8	9	10	11	12	13	(Zf)	Mean Z Score	Scale Value*
[illegible]	3	9	7	[illegible]	3	3	1	0	0	0	0	0	0	-27.07	-.873	.491
[illegible]	[illegible]	[illegible]	1	1	2	1	4	11	4	2	2	1	2	8.93	.238	1.652
Z Score Rank Equivalents	-1.77	-1.2	-.87	-.62	-.40	-.19	0	.19	.40	.62	.87	1.2	1.77			

* Scale Value = mean Z score transformed to eliminate negative values

Section 5

DISCUSSION

SCALING SUMMARY AND COMPARISONS

The primary goal of the effort presented in this report was to derive standardized communications tasks that could be used as highly realistic secondary tasks in R&D simulations and actual flight tests. In order to combine the tasks so that controlled levels of loading could be produced for specific applications, three methods of workload scaling were employed. The first technique was based on estimating the information transmission requirements of communications activities. Information metrics were found to be applicable to perceptual decisions and manual action decisions required in response to incoming messages and were used to generate an analytical scale for the 13 A-10 communications tasks. This approach was supplemented by a technique developed to estimate the additional contributions to workload of information gathering activities, memory demands, and instruction complexity which were not assessed by information theoretical measures. A paired comparisons method was used to obtain pilot opinions of the workload associated with individual instructional messages contained in the communications tasks. The results were used to produce a hybrid analytical scale representing both the information transmission demands and the information processing complexity of the tasks. The third set of workload estimates were obtained from pilot rankings of the total workload of entire communications tasks. Modified Thurstonian procedures were used to devise a normalized subjective scale.

Comparisons of the results of the three scaling methods were performed using nonparametric correlational techniques. Kendall's Coefficient of Concordance revealed a significant amount of overall agreement among the workload estimates ($W = .929$, $p < .01$). Since the analytical and hybrid analytical techniques shared data sources and, therefore, were not independent estimates, separate Spearman Rank Correlations were also computed between the individual scales. As expected, the analytical and hybrid analytical scales were highly correlated ($r_s = .979$, $p < .01$). However, there was also significant agreement between the subjective scale and the findings obtained with each of these methods (analytical, $r_s = .856$, $p < .01$; hybrid, $r_s = .824$, $p < .01$).

WORKLOAD THEORY AND SECONDARY COMMUNICATIONS TASKS

Efforts to assess mental workload using secondary tasks are complicated by a somewhat controversial theoretical climate. Currently, two general types of models of the human information processing system offer different recommendations about the manner in which secondary tasks should be implemented and about the way in which secondary task measures can be interpreted to make inferences about workload (see Hawkins and Ketchum, 1980; and Sanders, 1978 for reviews of specific models).

In one type of theory, mental capacity is viewed as a single undifferentiated resource which is shared among information processing functions. Accordingly, all primary and secondary tasks should draw from this common capacity and, barring peripheral task interference, the form of the secondary task should not bias the workload measure that is obtained. The scaling methods used in this project to estimate the workload of communications tasks reflect a concept of workload which depends upon the validity of this theory. That is, the communications tasks were assigned values on unidimensional scales of workload that did not differentiate between the information processing structures or functions employed by the task.

A second type of workload theory assumes that the information processing system has several structure-specific capacities. In its strong form, this model might be used to argue that the secondary task methodology is of limited value because obtained workload measures would be dependent upon the degree to which particular primary and secondary tasks share common mental functions, and therefore, common capacities. However, given an appropriate methodology, a multiple resource model can be accommodated by the secondary task technique. As Wickens (1979) has noted, if meaningful differences between processing functions can be identified and if secondary tasks to assess corresponding loading dimensions can be selected, the workload of a primary task of interest could be expressed as a structural loading profile.

At present, basic research efforts have failed to conclusively demonstrate that one of the models discussed above provides a better description of mental workload than the other. Consequently, it is impossible to determine whether the approach taken in this report to designing secondary communications tasks is completely adequate. However, should the controversy be resolved at a future date in favor of the multiple capacity model, the desirable features and advantages of the communications task method of workload assessment could be incorporated into a revised methodology. Specifically, it is entirely feasible that subsidiary radio communications tasks could be developed to tap individual processing resources.

FUTURE RESEARCH

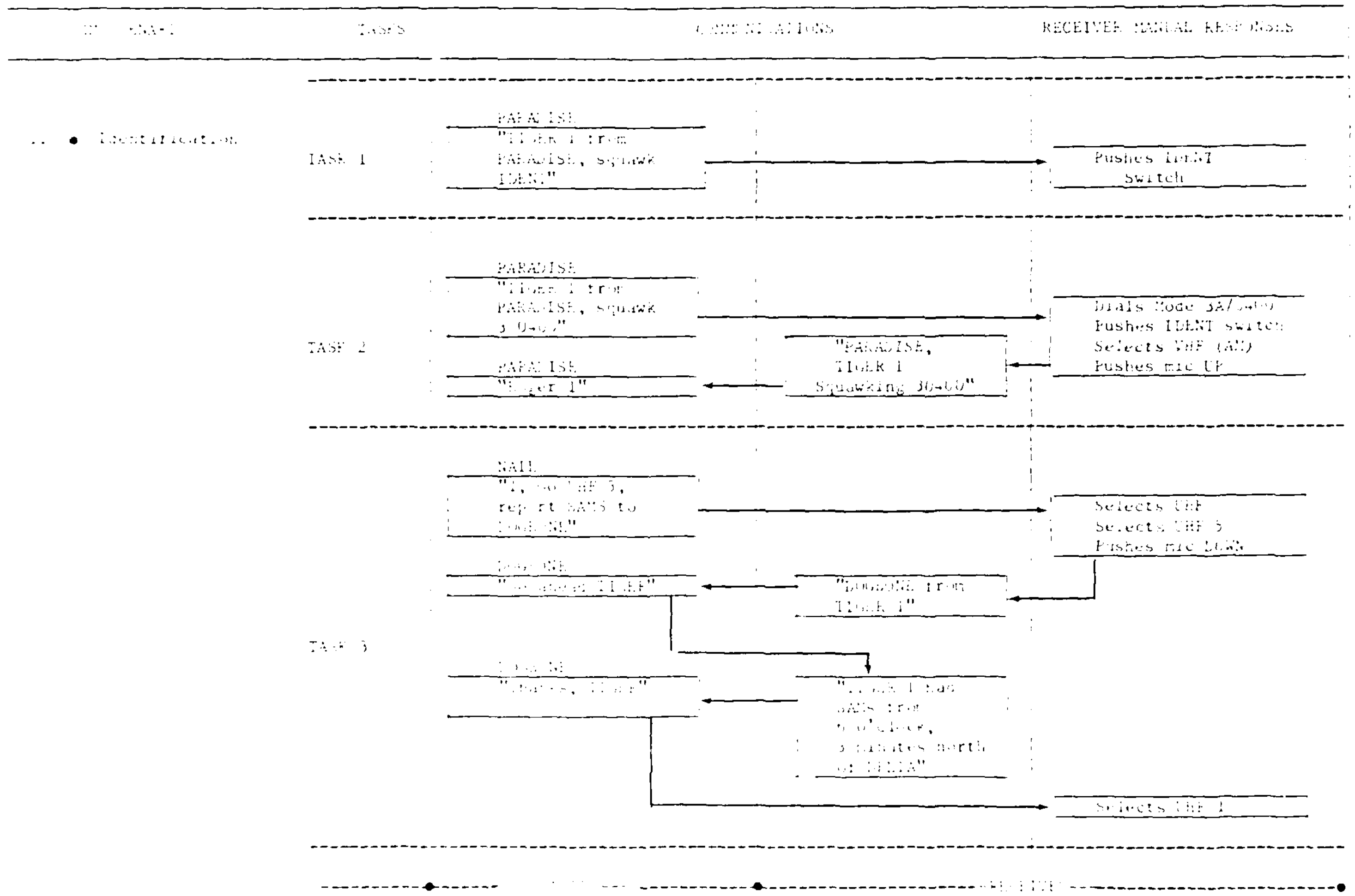
The development of the concept of using aircraft radio communications tasks for workload assessment and the use of a priori scaling techniques to estimate the workload associated with these tasks are initial steps toward designing a viable workload assessment methodology. A program of dual task performance research is needed to assess the sensitivity of workload measurement available with subsidiary communications tasks and to generate a criterion for validating the scaling technique.

Preliminary studies should examine the performance measures which can be derived from the verbal and manual behaviors associated with communications tasks in order to permit the selection of a limited set of indices which appear to be most sensitive to primary task workload. Once measures are obtained for each task, formal research must be conducted in which the tasks are performed by subjects in conjunction with primary aircrew duties at various levels of task demand.

The results of this study would serve two purposes. First, the obtained performance scores would allow an ordering of the tasks along a dimension of sensitivity to workload. These findings could then be used to determine the type and amount of subsidiary task activity needed to produce useful workload estimates. Second, the scores for each task could be used to assess the utility of the a priori scaling procedures. Although the correlations among the three scaling results provide evidence for convergent validity, the ultimate criterion for evaluating these methods is the task performance variation observed in a dual task environment such as that described above. Thus, the correlations between performance scores and each of the scale results cou'd be used to select an appropriate method of constructing communications tasks without resorting to exhaustive performance testing.

The experimental plan outlined above could be implemented in an austere flight simulation. Subjects would be asked to perform a primary tracking task and required to engage in simultaneous radio communications tasks using the radio panels from the A-10 aircraft. The results of this preliminary study would be used to guide future efforts with the radio communications task workload assessment methodology. Those tasks shown to be sensitive to rudimentary continuous control task workload could be evaluated at a higher level of fidelity of simulation. If close agreement was found between dual task performance and the results of any of the a priori scaling techniques, it would be possible to write generalized guidelines for the design of scaled sets of additional communications tasks. These procedures would then be made available to others to enable the development of workload measurement tasks tailored to specific systems, missions, and crew stations.

APPENDIX 1



TASKS
RECEIVER MANUAL RESPONSES
Identification
TASK 1
PARADISE
"TIGER 1 from PARADISE, squawk IDENT"
Pushes IDENT Switch
TASK 2
PARADISE
"Tiger 1 from PARADISE, squawk 3 0400"
Dials Mode 3A/3400
Pushes IDENT switch
Selects VHF (AM)
Pushes mic UP
"PARADISE, TIGER 1 Squawking 3400"
PARADISE
"Tiger 1"
TASK 3
NAIL
Selects UHF
Selects UHF 5
Pushes mic DOWN
"DOGBONE from TIGER 1"
"Thanks, Tiger"
Selects UHF 1

A-10 COMM WORKLOAD SCENARIOS BROKEN DOWN INTO TASKS (continued)

COMM SCENARIO	TASKS	COMMUNICATIONS		RELATIVE MANUAL RESPONSES
2. • Threat Alert	TASK 1	TIGER 2 "TIGER 1, Break SAM at 6 o'clock"	"Roger, 2"	Releases chaff, flares. Selects FM Pushes mic DOWN
	TASK 2	NAIL "1, go UHF 5, report SAMs to DOGBONE"	"ROGER NAIL"	Pushes mic DOWN
				Selects UHF 5 Pushes mic DOWN
		DOGBONE "Roger TIGER 1"	"DOGBONE, TIGER 1 has SAMs at 6 o'clock"	Selects UHF 1
		SENDER		RECEIVER

A-10 COMM WORKLOAD SCENARIOS BROKEN DOWN INTO TASKS (continued)

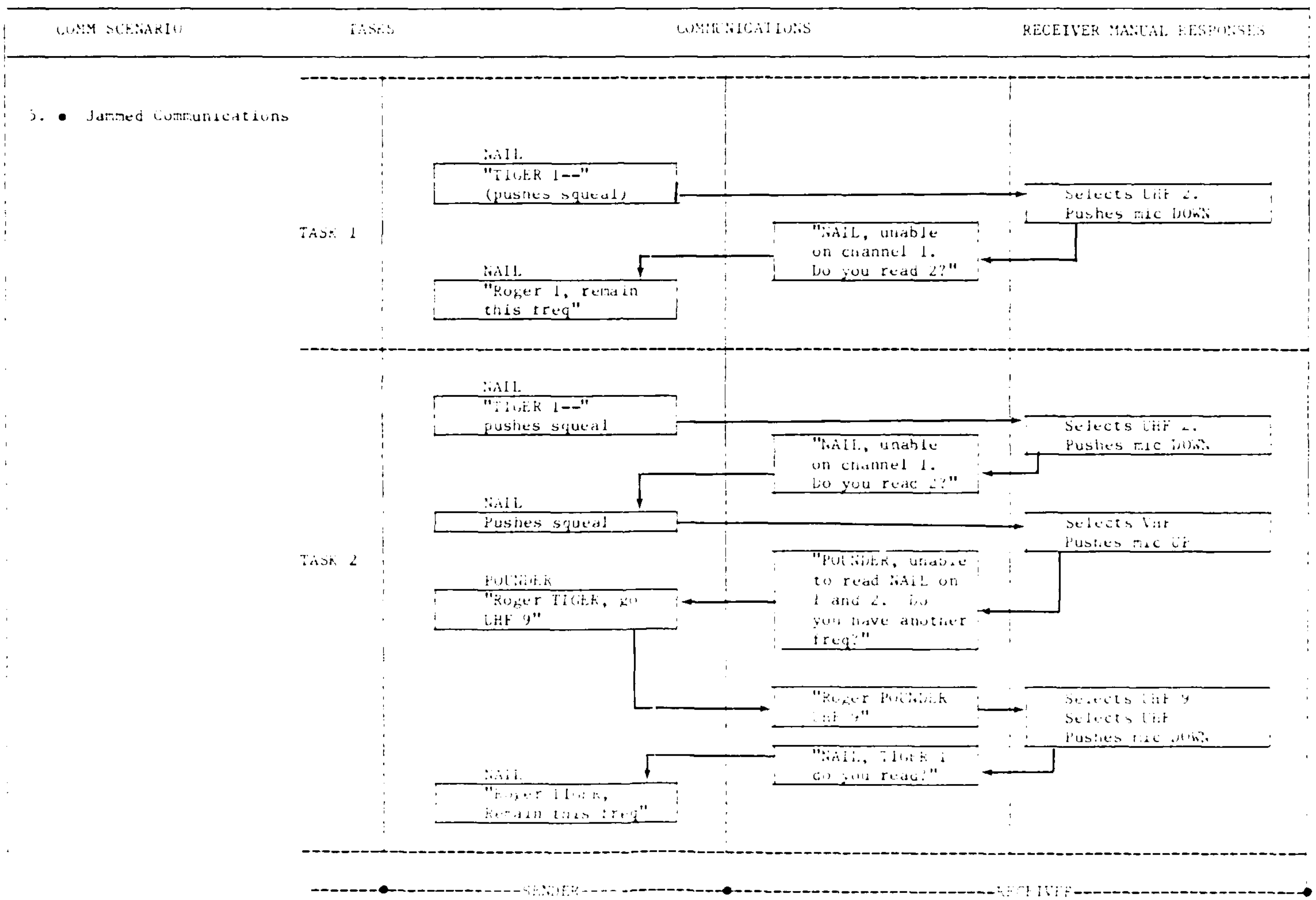
COMM SCENARIO	TASKS	COMMUNICATIONS		RECEIVER MANUAL RESPONSES
3. • Traffic Control	TASK 1	PARADISE "TIGER 1 from PARADISE, descend to and maintain base plus 3 immediately"		Turns mode to VHF(AM) Pushes mic DOWN
			"Roger PARADISE, going base plus 3 now"	Selects UHF
	TASK 2	PARADISE "TIGER 1 from PARADISE, descend to base plus 3, turn 90° right and hold for 1 minute. Report at altitude to POUNDER"		Turns mode to VHF Pushes mic DOWN
			"Roger PARADISE, base plus 3, 90° right for [illegible] minute, [illegible]"	
		PARADISE "Roger TIGER"		(After 1 minute) Selects VHF 9 (142.7) Pushes [illegible] DOWN
		POUNDER "Roger TIGER 1"	"POUNDER, TIGER [illegible] at base plus 3, [illegible]"	Selects UHF
		SENDER	RECEIVER	

A-10 COMM WORKLOAD SCENARIOS BROKEN DOWN INTO TASKS (continued)

COMM SCENARIO	TASKS	COMMUNICATIONS		RECEIVER MANUAL RESPONSES
4. ● Waypoint Passage	TASK 1	NAIL "TIGER 1, call 1 minute out of Bravo"	"Roger NAIL"	Pushes mic DOWN
		NAIL "Roger, 1"	"NAIL, TIGER 1 out of Bravo now"	(1 min past BRAVO) Pushes mic DOWN
	TASK 2	NAIL "TIGER 1, call FRIENDLY 1 min out of Bravo on UHF 132.1"	"Roger NAIL"	Pushes mic DOWN
		FRIENDLY "Roger TIGER 1"	"FRIENDLY, TIGER 1 is out of Bravo, now"	(1 min past Bravo) Turns UHF to 132.1 Turns UHF mode to MANUAL Pushes mic DOWN
		NAIL "Roger 1"	"NAIL, TIGER 1 back on your freq"	Turns UHF channel to 1 Turns UHF mode to PRESET Pushes mic DOWN

SENDER — RECEIVER

A-10 COMM WORKLOAD SCENARIOS BROKEN DOWN INTO TASKS (continued)



A-10 COMM WORKLOAD SCENARIOS BROKEN DOWN INTO TASKS (continued)

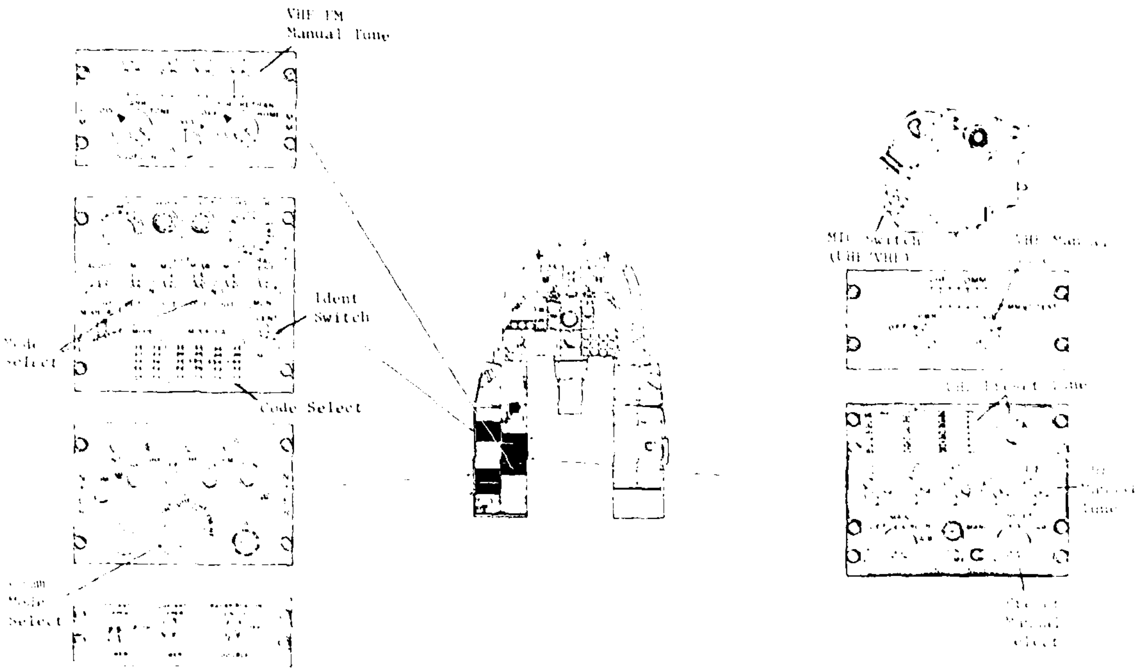
COMM SCENARIO	TASKS	COMMUNICATIONS (SENDER)	COMMUNICATIONS (RECEIVER)	RECEIVER MANUAL RESPONSES
b. • Strike Clearance	TASK 1	NAIL "TIGER 1, call IP. NAIL marking now with smoke. Call in hot at pop"		Pushes mic DOWN
			"Roger NAIL"	(at IP) Pushes mic DOWN
			"NAIL, 1's at IP"	
		NAIL "Roger 1"		(at pop-up) Pushes mic DOWN
			"NAIL, 1's in hot"	
		NAIL "Roger 1, you're clear"		
	TASK 2	NAIL "TIGER 1, call IP. NAIL marking now with smoke. Call in hot at pop"		Pushes mic DOWN
			"Roger NAIL"	(at IP) Pushes mic DOWN
			"NAIL, 1's at IP"	(at pop-up) Pushes mic DOWN
		NAIL "ROGER 1"		
			"NAIL, 1's in hot"	(at target recognition) Pushes mic DOWN
		NAIL "Roger, call target in sight"		
			"Talleyho"	
		NAIL Roger 1, call clear to TIGER 2"		
			"Two, 1's clear"	(after strike) Selects FM Pushes mic UP
		TIGER 2 "Roger 1"		Selects UHF

SENDER — RECEIVER

APPENDIX 2

A-10 COMMUNICATION CONTROLS

AND SWITCH POSITIONS AND PROCEDURES FOR MISSION START



A-10 Communication Controls

A-10 SWITCH POSITIONS AND PROCEDURES FOR MISSION START

Radio Panel	Control	Control Position
UHF	Present Channel Card	#1 marked 259.4 #2 marked 328.2
	Channel Selection	1
	Frequency Selectors	178.3
	Mode	PRESET
	Squelch	ON
	Volume	12 o'clock
	Function	MAIN
INTERCOM	Volume	12 o'clock
	Monitor Switches	UHF, VHF, FM are UP UHF, FM volumes set higher than VHF HM, INT, HF, IFF, ILS, TCN are DOWN
	Rotary	UHF
ANTENNA SELECT	IFF, UHF	Both
	Radar	Off
VHF/AM	Power	Power
	Frequency Indicator	122100
	Volume	12 o'clock
VHF/FM	Squelch	Carrier
	Frequency Selectors	4080
	Mode	T/R
IFF	Master	Normal
	M-2, M-6	On
	M-1, M-3/A	Off
	Rad Test	(Inop)
	Ident	Out
	Mode 3/A	0102
	Mode 1	23
	Mode 4	Out
	Audio	Out
	Code	A
TRANSMIT	Mic Switch	VHF is UP, UHF is DOWN

A-10 SWITCH POSITIONS AND PROCEDURES FOR MISSION START (continued)

Radio Panel	Control	Control Position
THREAT	*Engine Restart*	Left switch is CHAFF Right switch is FLARES
UHF Remote Frequency Indicator	(not used for this report)	

TIGER's radios are powered ON and tuned, and his INTERCOM is set to monitor UHF, FM, and AM and transmit on UHF. During lost or jammed communication, TIGER is to try alternate frequencies then check for new frequency with POUNDER. TIGER should always return to UHF (transmit) unless otherwise directed.

APPENDIX 3

TASK WORKLOAD VALUES

Scenario			No. of Bits
I. Identification Demand			
	A. Task 1		
		1. Sender ID	2.585
		2. Receiver ID	2.585
		3. Push IDENT button	1.000
		TOTAL	6.170
	B. Task 2		
		1. Sender ID	2.585
		2. Receiver ID	2.585
		3. IFF Code Select Mode	1.000
		4. IFF Mode 3A/0400 Select	12.000
		5. Push IDENT button	1.000
		6. Select VHF/AM	1.585
		7. Push microphone	1.000
		8. Confirm	1.000
		TOTAL	22.755
	C. Task 3		
		1. Sender ID	2.585
		2. Receiver ID	2.585
		3. Select UHF Preset Channel 5	4.322
		4. Push microphone	1.000
		5. Call DOGBONE	2.585
		6. Report	1.000
		7. Select UHF Preset Channel 1	4.322
		TOTAL	18.399

TASK WORKLOAD VALUES (continued)

Scenario	No. of Bits
II. Threat Alert	
A. Task 1	
1. Sender ID	2.585
2. Receiver ID	2.585
3. Release chaff	1.000
4. Release flares	1.000
5. Select FM	1.585
6. Push microphone	1.000
7. Confirm	1.000
	TOTAL 10.755
B. Task 2	
1. Sender ID	2.585
2. Receiver ID	2.585
3. Push microphone	1.000
4. Confirm	1.000
5. Select UHF Preset Channel 5	4.322
6. Push microphone	1.000
7. Call DOGBONE	2.585
8. Report	1.000
9. Select UHF Present Channel 1	4.322
	TOTAL 20.399
III. Traffic Control	
A. Task 1	
1. Sender ID	2.585
2. Receiver ID	2.585
3. Select VHF/AM	1.585

TASK WORKLOAD VALUES (continued)

Scenario			No. of Bits
	A.	Task 1 (continued)	
		4. Push microphone	1.000
		5. Confirm	1.000
		6. Select UHF	1.585
			TOTAL 10.340
	B.	Task 2	
		1. Sender ID	2.585
		2. Receiver ID	2.585
		3. Select VHF	1.585
		4. Push microphone	1.000
		5. Confirm	1.000
		6. Select VHF 9 (147.7)*	11.966
		7. Push microphone	1.000
		8. Report to POUNDER	2.585
		9. Select UHF	1.585
			TOTAL 25.891
IV.	Waypoint Passage		
	A.	Task 1	
		1. Sender ID	2.585
		2. Receiver ID	2.585
		3. Push microphone	1.000
		4. Confirm (memory)	1.000
		5. Push microphone	1.000
		6. Report to NAIL	2.585
			TOTAL 10.755

(*Assume POUNDER is on same VHF channel and there are no presets)

TASK WORKLOAD VALUES (continued)

Scenario			No. of Bits
	B.	Task 2	
		1. Sender ID	2.585
		2. Receiver ID	2.585
		3. Push microphone	1.000
		4. Confirm (memory)	1.000
		5. Select UHF (132.1)	12.966
		6. Select UHF Manual	1.585
		7. Push microphone	1.000
		8. Call FRIENDLY and report	2.585
		9. Select UHF Preset	1.585
		10. Push microphone	1.000
		11. Call NAIL and report	2.585
			TOTAL 30.476
V.	Jammed Communications		
	A.	Task 1	
		1. Sender ID	2.585
		2. Receiver ID	2.585
		3. Change channels	1.000 (if no set procedure)
		4. Push microphone	1.000
		5. Call NAIL, check for usable frequency	2.585
			TOTAL 9.755
	B.	Task 2	
		1. Sender ID	2.585
		2. Receiver ID	2.585
		3. Change channels	1.000
		4. Push microphone	1.000

TASK WORKLOAD VALUES (continued)

Scenario			No. of Bits
	B.	Task 2 (continued)	
		5. Call NAIL and report	2.585
		6. Change channels	1.000
		7. Push microphone	1.000
		8. Call POUNDER, request frequency	2.585
		9. Confirm	1.000
		10. Select UHF	1.585
		11. Select channel	4.322
		12. Push microphone	1.000
		13. Call NAIL and report	2.585
			TOTAL 24.832
VI.	Strike Clearance		
	A.	Task 1	
		1. Sender ID	2.585
		2. Receiver ID	2.585
		3. Push microphone	1.000
		4. Confirm (memory)	1.000
		5. Push microphone	1.000
		6. Call NAIL and report IP (memory)	2.585
		7. Push microphone	1.000
		8. Call NAIL and report Pop-up	2.585
			TOTAL 14.340
	B.	Task 2	
		1. Sender ID	2.585
		2. Receiver ID	2.585
		3. Push microphone	1.000
		4. Confirm (memory)	1.000

TASK WORKLOAD VALUES (continued)

Scenario			No. of Bits
B.	Task 2 (continued)		
	5.	Push microphone	1.000
	6.	Call NAIL and report IP (memory)	2.585
	7.	Push microphone	1.000
	8.	Call NAIL and report Pop-up (memory)	2.585
	9.	Push microphone	1.000
	10.	Call NAIL and report Target Recognition (memory)	2.585
	11.	Select VHF/FM	1.585
	12.	Push microphone	1.000
	13.	Call Tiger 2 and report Clear	2.585
	14.	Select UHF	1.585
		TOTAL	24.680

APPENDIX 4

INSTRUCTIONS AND SAMPLE PAGE FROM

PAIRED COMPARISONS

TEST BOOKLET INSTRUCTIONS

The purpose of this study is to get pilot opinions on the workload associated with tasks that you are required to perform in response to particular radio messages. You will be asked to compare a number of messages containing instructions that you might receive during an air-to-ground attack mission. The comparisons will be performed in pairs.

When evaluating the instructions, you should try to consider all of the visual, mental, manual, and verbal activities that you would have to engage in and their effects on the workload you would experience. Although the individual instructions may be taken from particular mission segments which differ in the total amount of workload associated with them, we want you to try to evaluate only the workload imposed upon you by the specific instruction. Try not to confuse the workload level of the primary mission or the combat situation with your perception of the workload due to the instructions received over the radio.

For each pair, we want you to <u>place a check</u> next to the instruction which requires you to invest the greater amount of effort to carry out (i.e., which has the higher workload). DO THIS NOW.

	✓	SENDER	MESSAGE
9 - 12	______	FAC	Call in hot at POP.
	______	AWACS	Squawk IDENT.
10 - 13	______	FAC	Call target in sight.
	______	AWACS	Squawk 3, 0400.
11 - 14	______	FAC	Call clear to TIGER 2.
	______	FAC	Go to UHF 5
12 - 15	______	AWACS	Squawk IDENT.
	______	TIGER 2	Break left, SAM at 6 o'clock.
1 - 5	______	AWACS	Report SAMS
	______	AWACS	Descend to base plus 3, turn 90 degrees right, hold for 1 minute. Report at altitude.

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